

M-Series: Fast Silicon Photomultiplier Sensors

SensL's M-Series sensors feature a uniquely fast output signal that can have a rise time of ~100 ps and a recovery time of <1 ns, allowing for precision timing and fast count rates. The M-Series sensors are available in four sensor sizes (0.25 mm, 1 mm, 3 mm and 6 mm) and a number of package types, including a 4-side tileable surface-mount (SMT) package that is compatible with lead-free, reflow soldering processes.



The MicroFM sensors are based on the silicon photomultiplier concept and form a range of high gain, single-photon sensitive, visible-light sensors. They have performance characteristics similar to a conventional PMT, while benefiting from the practical advantages of solid-state technology: low operating voltage, robustness, compactness and insensitivity to light over-exposure. More information on the M-Series sensors, including their performance characteristics, can be found in the [M-Series Datasheet](#).

Overview

The M-Series SiPM sensors from SensL are based on a N-on-P diode structure (Figure 1) that results in a broad range of sensitivity from 400 nm to 1000 nm.

All M-Series SiPM sensors also feature SensL's proprietary *fast output* terminal (Figure 2), giving access to signals with extremely fast rise times and short pulse widths.

M-Series SiPM products are available in either MicroSM (2-pin) or MicroFM (3-pin) versions.

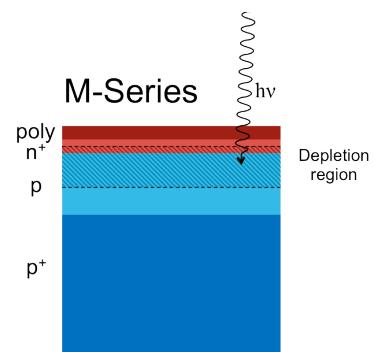


Figure 1, N-on-P sensor structure

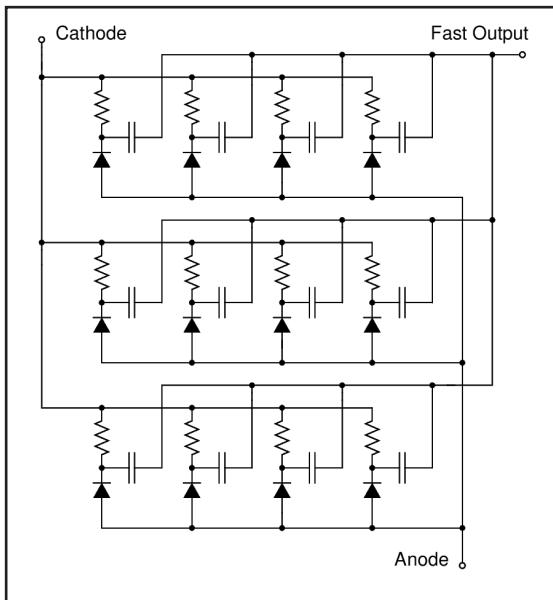


Figure 2, Simplified microcell level schematic of the M-Series SiPM.

MicroSM

Although all M-Series SiPM sensors have the architecture shown in Figure 2, MicroSM packaged products only have two pins giving access to the *anode* and *cathode*. The *fast output* is **not** accessible in MicroSM products.

MicroFM

MicroFM packaged products have three (or more) pins, giving access to the *fast output* as well as the *anode* and *cathode*. The *fast output* is the derivative of the internal fast switching of the microcell in response to the detection of a single photon.

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Glossary

M-Series - A family of SiPM products based upon a N-on-P structure, with broad spectral sensitivity.

FM - M-Series SiPM product that has at least 3 pins (or pads) accessible that include *anode*, *cathode* and the *fast output* and can therefore be used in *fast mode* configuration.

SM - M-Series SiPM product that has only 2 pins, giving access to the *anode* and *cathode*. The third terminal (fast output) is not accessible, and so SM sensors can only work in *standard mode*.

Fast mode - Using the *fast output* signal from an FM product for improved timing or photon counting applications.

Standard mode - Using the signal from the *anode* and *cathode* for the readout of an SM or FM product where timing performance is less critical.

Biassing and Readout

Fast Mode Biassing and Readout of MicroFM Sensors

Recommended Fast Mode Biassing

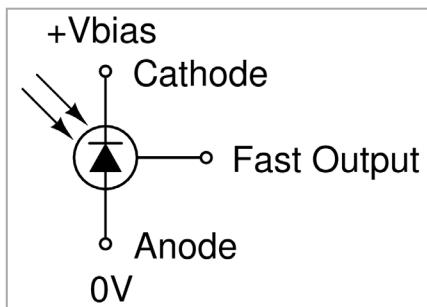


Figure 3, Recommended biassing

The fast output is referenced to the *anode* (substrate) of the SiPM. Therefore the use of a positive bias voltage applied to the *cathode* with the *anode* at 0 V is recommended, as in Figure 3. The *fast mode* signal polarity is negative. (If an application requires the use of a negative bias, please refer to the advice in Appendix A.) Please refer to the [M-Series datasheet](#) for operating over-voltage range.

The observed signals will be very fast, with rise-times ranging from 100 ps to 1ns and pulse widths of ~400 ps - 5 ns (depending on sensor size). A typical output pulse for a 3 mm sensor (MicroFM-30035) is shown in Figure 4.

For all application circuits shown in this User Manual, it is recommended that a bias voltage filter, such as the one shown in Figure 5, is used.

Recommended Fast Mode Readout

Due to the extreme speed of the signals from the *fast output*, care should be taken in the routing of the signal. Common microwave/RF design rules, such as controlled impedance microstrip lines, should be used. The capacitance of the fast output electrode is much lower (of the order of 2-3 pF for a 1 mm device) than in a standard configuration. The lower output capacitance does not typically allow the use of a transimpedance amplifier, and instead one can use an RF style (50 Ω impedance) solution including direct connection to a coaxial cable. The 3 mm and 6 mm devices have higher capacitance, so for best operation when connecting to an oscilloscope or driving long wires, it is recommended that the fast output be connected to an RF transformer such as the RFXF9503 as in Figure 7. This provides impedance matching, to improve amplitude and timing characteristics of the pulse for 50 Ω impedance. For 1 mm devices the capacitance is low enough to allow direct 50 Ω connection as in Figure 6. Another feature of the *fast output* electrode is that it is AC-coupled, with no DC component. However, if needed, one can combine it with the standard output (see the next section) of the SiPM to incorporate DC information.

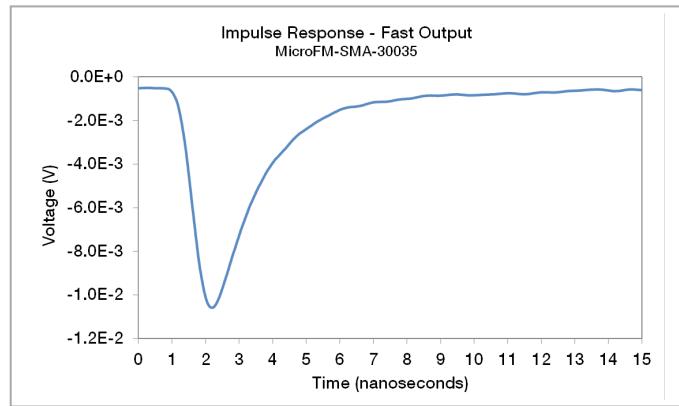


Figure 4, Fast mode output of a MicroFM-30035 when illuminated with a 40 ps laser pulse (Photek LPG-405).

Fast Output Amplification

It is important to note that the signal charge injected into the fast output electrode is typically about 2% of the SiPM charge generated during the avalanche. However, the pulse duration is also approximately 100 times shorter, so the current amplitude observed is about $0.02 * 100 = 2$ times higher. This high current amplitude, in combination with the significantly lower output capacitance, make the device suitable for photon counting at very high speed (tens of MHz and higher has been demonstrated in the lab).

For amplification of the fast signal it is recommended that a low noise 50 Ω RF amplifier be used. As with standard readout, the level of gain required is dependent on the application. For applications with high photon counts it is recommended that the Mini-Circuits ZX60-43S+ be used. For photon counting applications it is recommended that the Mini-Circuits ZFL-1000LN+ be used. For PET applications it is possible to obtain both timing and energy resolution information from the fast output, with the anode and cathode only used for biasing.

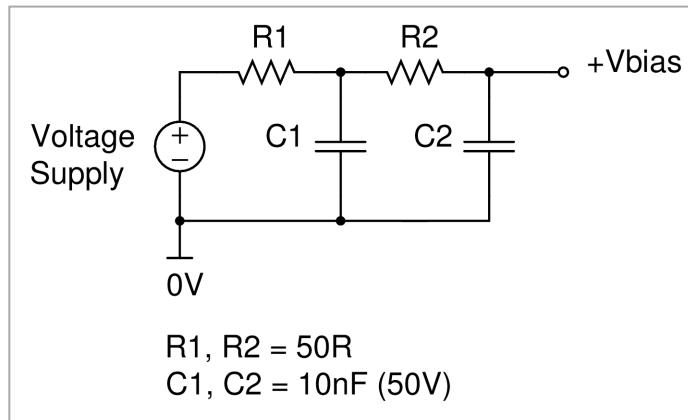


Figure 5, Generic biasing filter, recommended for all circuits given in this User Manual.

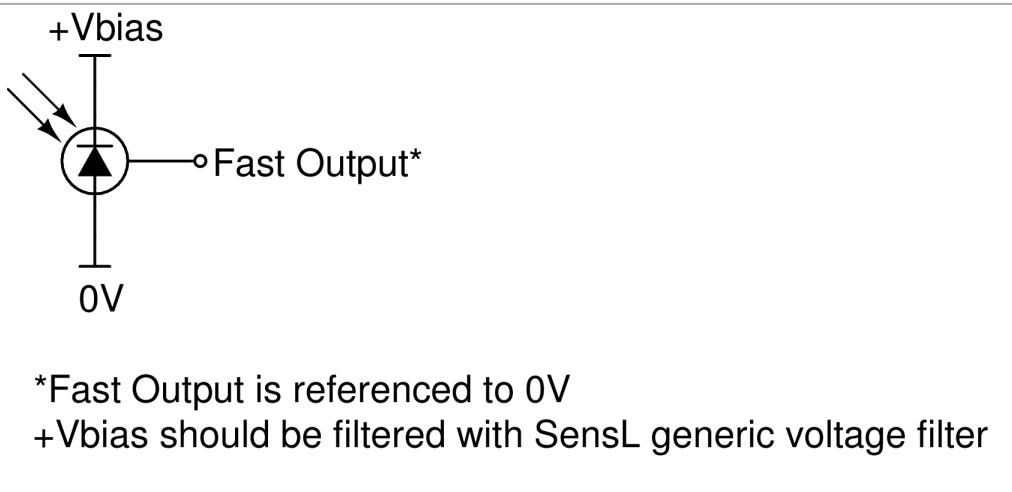


Figure 6, Recommended fast SiPM readout circuitry for 1 mm MicroFM sensors.

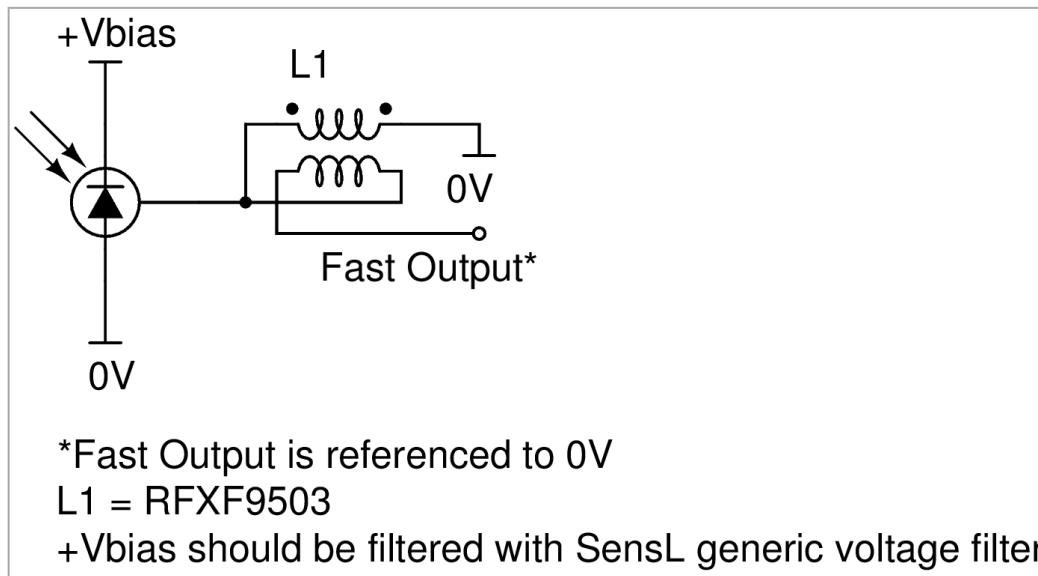


Figure 7, Recommended fast SiPM readout circuitry for 3 mm and 6 mm MicroFM sensors. Also shown is the recommended transformer part number and pin-out labelling.

Standard Mode Biasing and Readout of M-Series Sensors

For applications that do not require fast timing from the MicroFM, or for the MicroSM products that do not give access to the *fast output* signal, SensL's M-Series sensors will perform as a conventional SiPM. For MicroFM products the *fast output* terminal can be left open with no detriment to its *standard mode* performance. Standard mode signals may be more suitable for applications involving slow pulses or slowly-varying, continuous light levels, such as in luminometers or for gamma-ray spectroscopy with slow or low-light scintillators.

Recommended Standard Mode Biasing

Figure 8 below shows the *standard mode* biasing configuration. For MicroFM sensors the *fast output* electrode is left open (unconnected). For all M-Series sensors read out in standard mode, the cathode should be held at a positive bias with reference to the anode. It is recommended that the signal is taken from the side of the sensor held at 0V. Reading out in this way yields a pulse that has a rise time of 1 ns - 10 ns and a decay time of several hundred ns (depending on sensor and microcell size). A typical standard mode output pulse shape is shown in Figure 9.

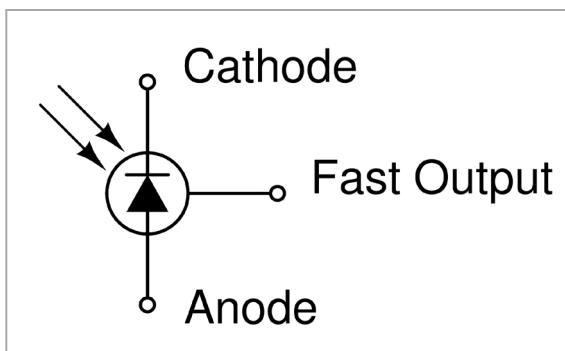


Figure 8, *Biasing for standard mode*. The cathode should be positive with respect to the anode, but either a positive or negative bias can be used.

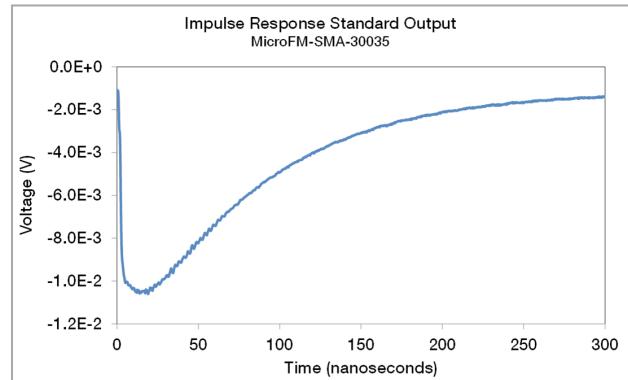


Figure 9, *Standard mode signal from a MicroSM-30035 when illuminated with a 50 ps laser pulse*.

Recommended Standard Mode Readout and Amplification

Figure 10 shows how the M-Series devices can be connected to a standard high speed amplifier, such as the OPA656, to convert the standard mode output signal current to a voltage. This technique is recommended for standard mode readout of all SensL SiPM devices. In the case of MicroFM devices the fast output can be left open.

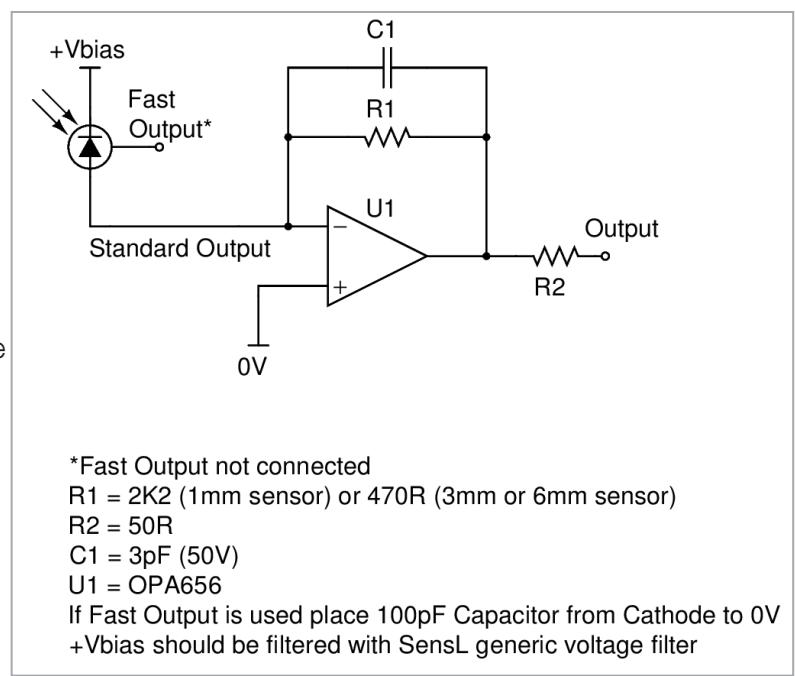


Figure 10, *Example readout circuit for standard mode*.

Dual Mode Readout of MicroFM Sensors

It is possible to read out both *fast* and *standard outputs* simultaneously from the sensor to obtain two separate signals. This can be used for obtaining timing (*fast output*) and amplitude information (*standard output*) from separate channels. This could be useful for applications such as PET (Positron Emission Tomography) where timing and energy information are required from each photon pulse. Note that this is only possible with MicroFM sensors. AC and DC coupled options for connecting the device for dual readout are shown in Figures 11 and 12.

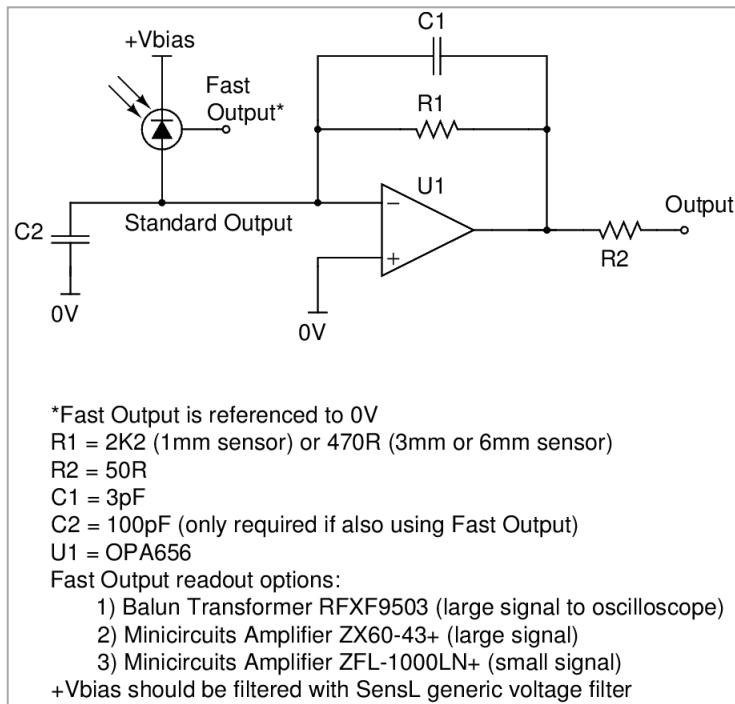


Figure 11, DC coupled readout option.
The standard output is amplified
through a transimpedance amplifier
(TIA).

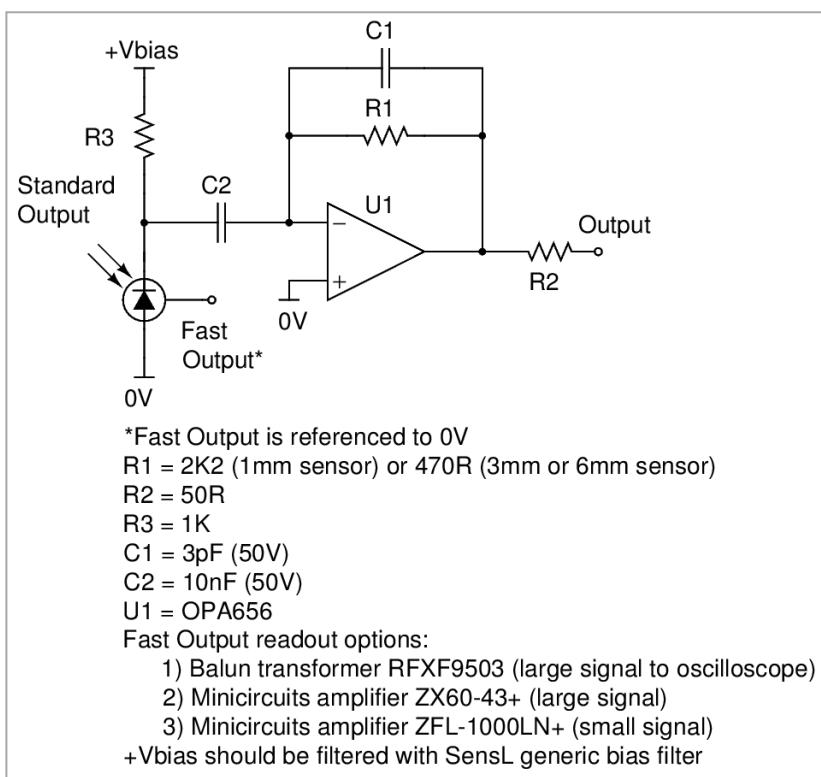


Figure 12, AC coupled readout option.
DC information from the SiPM is lost
but the pulse amplitude is maintained
through the transimpedance amplifier
(TIA).

A third option for simultaneous readout of the *standard* and *fast outputs* provides a DC coupled standard output signal, and preserves the ability to read out the *fast output*. The decoupling capacitor from the cathode to 0 V is critical to provide a return path for the *fast output*. This circuit is used on the SensL -SMA and -SMTPA evaluation boards. SensL recommend the +Vbias readout options from Figures 11 and 12 for most system designs.

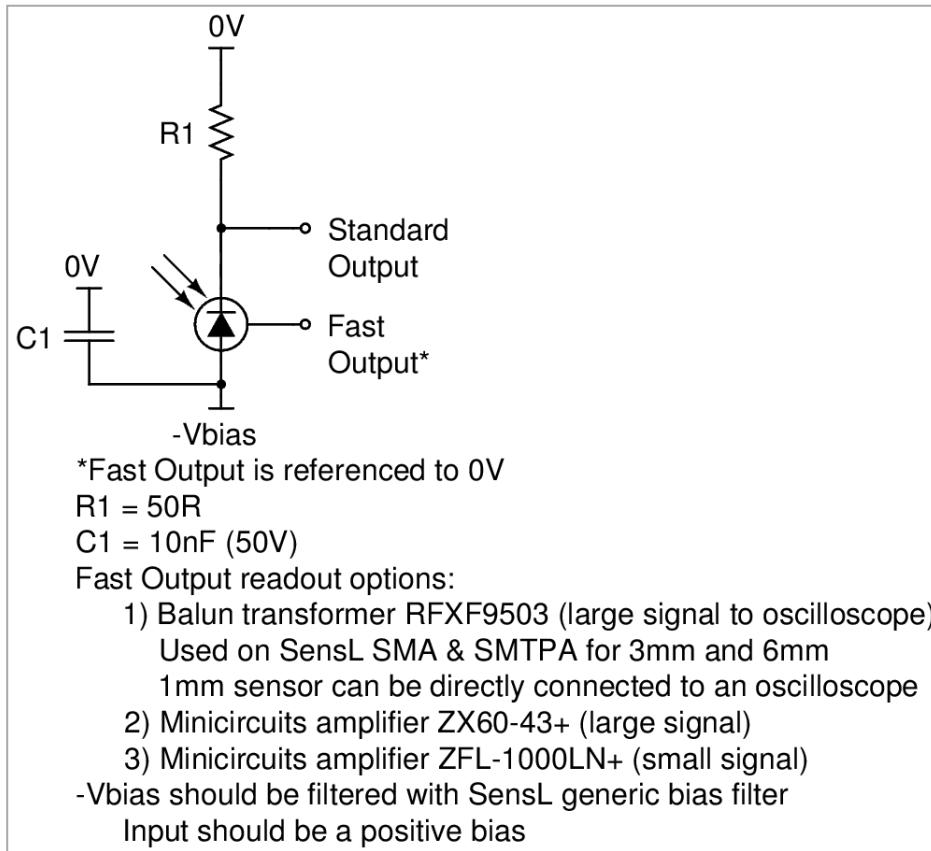


Figure 13, Third option for dual readout that is employed on the SensL -SMA and -SMTPA evaluation boards. Further information on using a negative bias is given in Appendix A.

Readout of Arrays of SiPM Devices

Many applications require the use of multiple sensors in the form of an array, such as the SensL Array-SMT line of products. Large arrays can pose a readout challenge due to the many channels of amplification and processing that are required. Therefore, methods of reducing the number of channels are often employed in order to reduce the readout requirements. Many examples of this can be found in the literature, and SensL has extensive experience in developing solutions for array readout, as demonstrated by the Matrix family of products. Please contact [SensL](#) to request a Tech Note on the subject of large area array readout.

M-Series Mounted Sensors

Some M-Series sensors are available ready mounted on test boards, to allow for easy evaluation. The -SMA and -SMTPA were designed for evaluation of both the *fast output* and the DC-coupled *standard output*. These boards use the circuit shown in Figure 13. The use of these boards is detailed in the following sections.

MicroFM-SMA

The MicroFM-SMA-XXXXX product line (Figure 14) features either an SMT or X18 packaged SiPM sensor (type specified by the XXXXX digits) soldered onto a small PCB board. The board is simple to use, having just three SMA connectors: one delivers the bias voltage (V_{bias}) and the other two provide the output signals: *standard output* from the cathode (S_{out}) and the *fast output* (F_{out}). The circuitry on the board is designed to bias the sensor in such a way as to preserve the optimum high-speed performance. A typical output pulse is shown in Figure 4 which was taken from a MicroFM-SMA-30035. The circuitry used is as given in Figures 13.

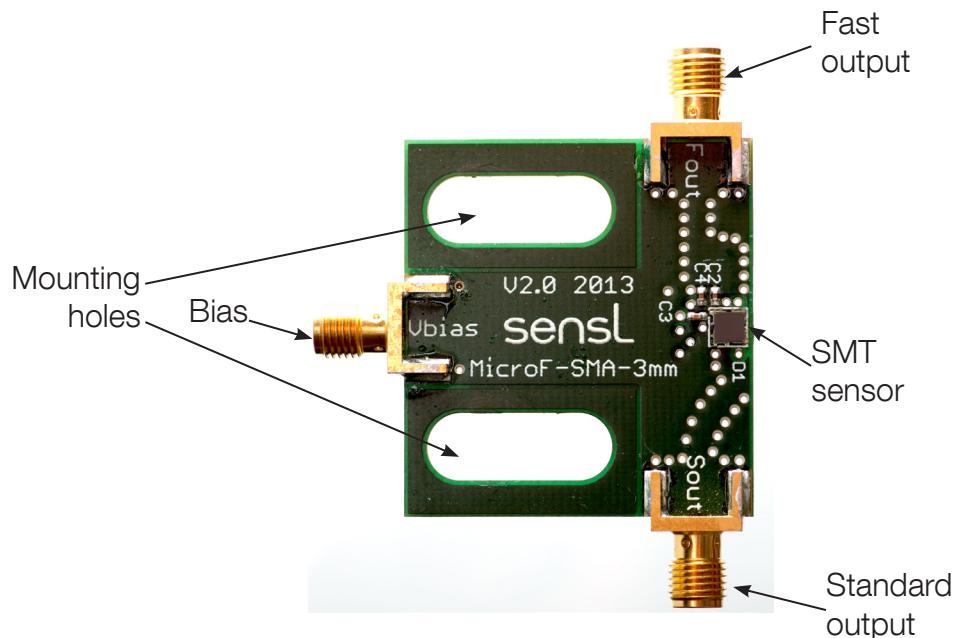


Figure 14, The MicroFM-SMA board: 3mm SMT version

Output	Function	Comments
V_{bias}	bias input (anode)	negative bias
F_{out}	fast output	if unused can be left open
S_{out}	standard output (cathode)	if unused can be left open

Table 1, SMA connections.

The MicroFM-SMA is recommended for users who require a plug-and-play set-up to quickly evaluate MicroFM sensors with optimal timing performance. The board provides outputs which can be connected directly to the oscilloscope or measurement device. The board also allows the *standard output* from the cathode to be observed at the same time as the *fast output*. Table 1 summarizes the connections to the SMA board.

Each board has two mounting holes to allow secure placement during testing, with sensors located at the edge of the board. This allows two sensors to be placed in close proximity for coincidence timing measurements.

MicroFM-SMTPA

The MicroFM-SMTPA-XXXX, or Pin Adapter board (Figure 15), features an SMT-packaged SiPM sensor (type specified by the XXXXX digits) mounted onto a small PCB board. The PCB has five through-hole pins that allow easy electrical connections to the electrodes of the SMT sensor. The pins are labeled on the PCB with numbers 1 - 5. Each of the numbered pins is connected as listed in Table 2, with the option to use either a positive or negative bias.

Pin No.	Connection	Function	
		Positive bias	Negative bias
1	cathode	positive bias input	standard output (if unused connect to zero V)
2	fast	fast output (if unused can be left open)	fast output (if unused can be left open)
3	anode	standard output (if unused connect to zero V)	negative bias input
4	gnd	PCB gnd	PCB gnd
5	n/c	do not connect	do not connect

Table 2, Pin connections for the MicroFM-SMTPA board

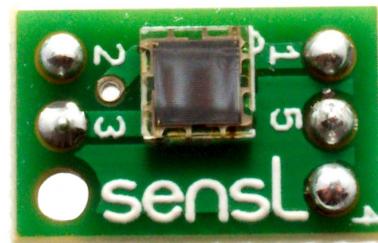


Figure 15, Pin numbering on the MicroFM-SMTPA board

The biasing circuit of the SMTPA is the same as on the SMA board (as indicated by Figure 13), however it does not contain any on-board decoupling on the bias line. Therefore, a bias filter, such as that in Figure 5, should be included on the bias line before connecting to the relevant bias input pin (see Table 2). The standard output can be connected directly to an amplifier or 50Ω load oscilloscope. If the standard output is not used, then that pin should be connected to zero Volts.

NOTE: The presence of the pins will slightly degrade the *fast output* signal from the sensor.

The connectors from Samtec used are:

BBL-103-G-E

BBL-102-G-E

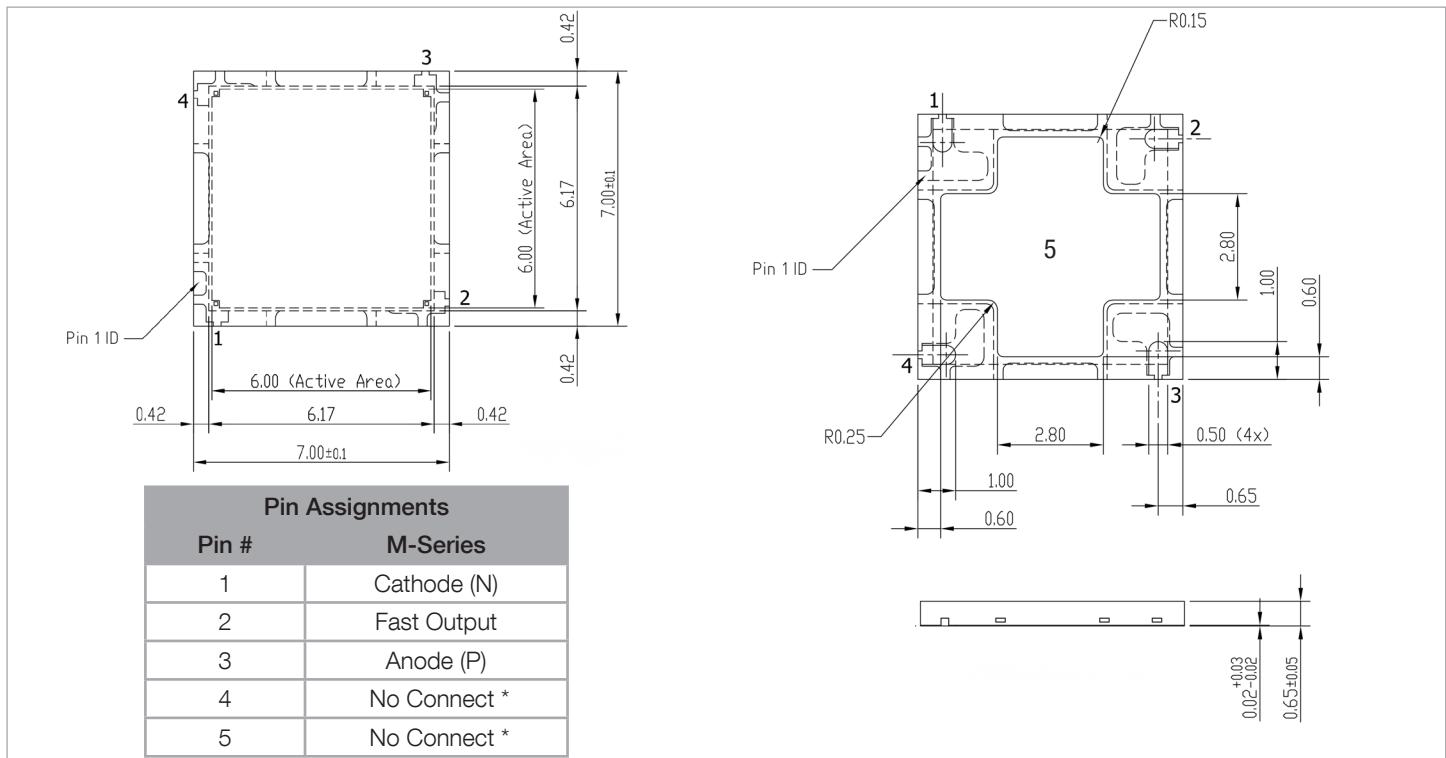
Compatible sockets from Samtec are:

SL-103-G-10

SL-102-G-10

Schematics, Pin/Pad Identification and Solder Footprint

MicroFM 60000 Series SMT Package



* No Contact (NC) pin 4 should be soldered to PCB, this pin can be connected to ground but it can also be left floating without affecting the dark noise. Recommend that NC pin 5 paddle is not soldered to the PCB and left floating to achieve optimal soldering on pins 1 to 4. Care must be taken to ensure that no electrical contacts on the PCB, such as vias, short out on the paddle if using the area underneath for routing. If it is desired to solder pin 5 to the PCB, for example to heatsink or ground the paddle, please consult your contract manufacturer for their solder recommendations based on their equipment and capabilities.

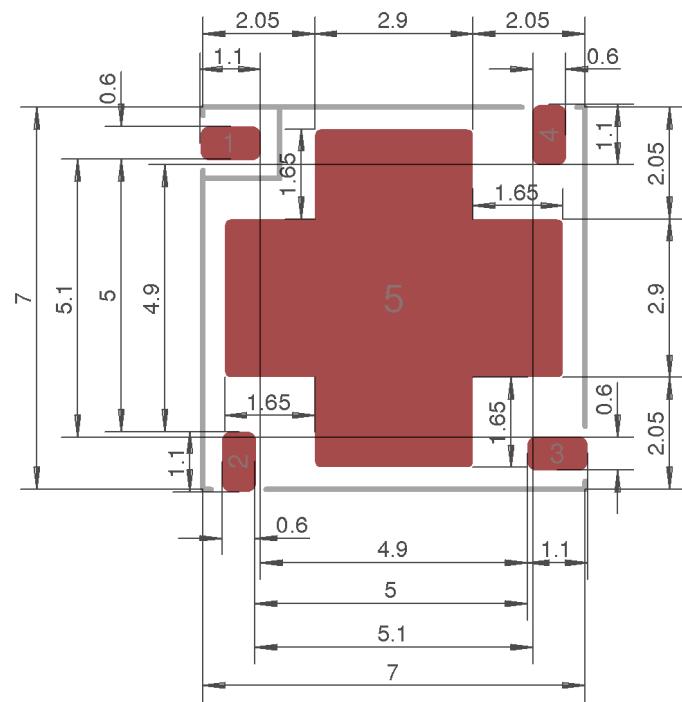
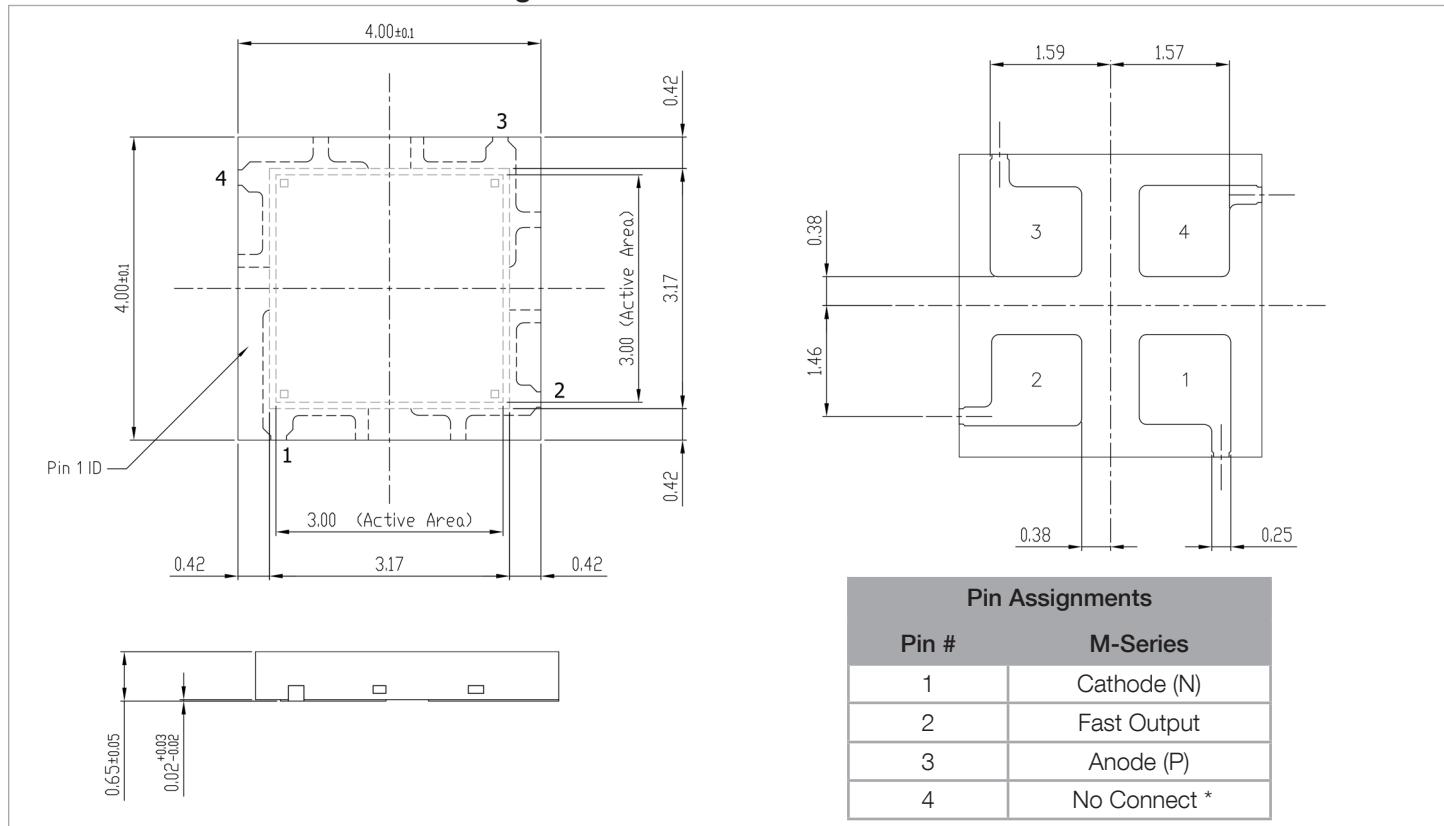


Figure 16, Solder footprint for the MicroFM-600XX-SMT part. All dimensions in mm.

MicroFM 30000 Series SMT Package



* No Contact (NC) pin 4 should be soldered to PCB, this pin can be connected to ground but it can also be left floating without affecting the dark noise.

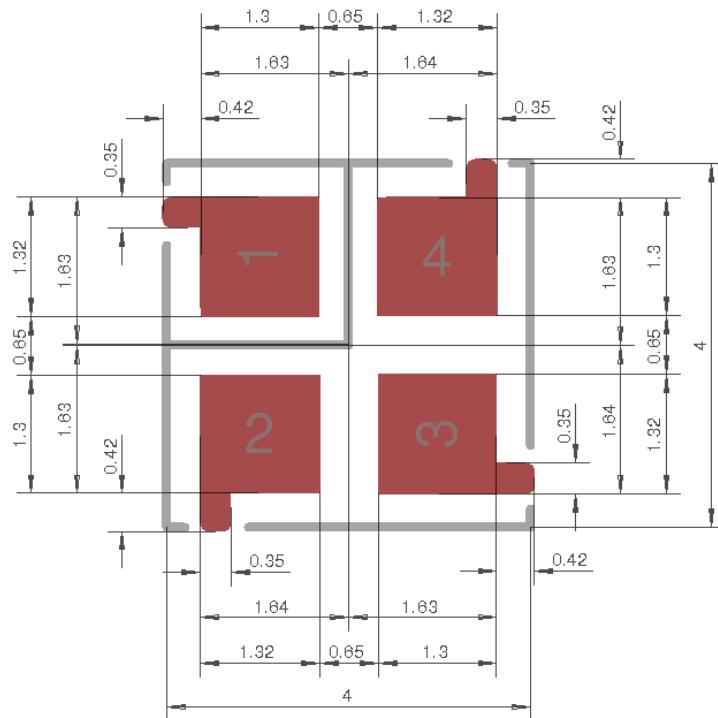
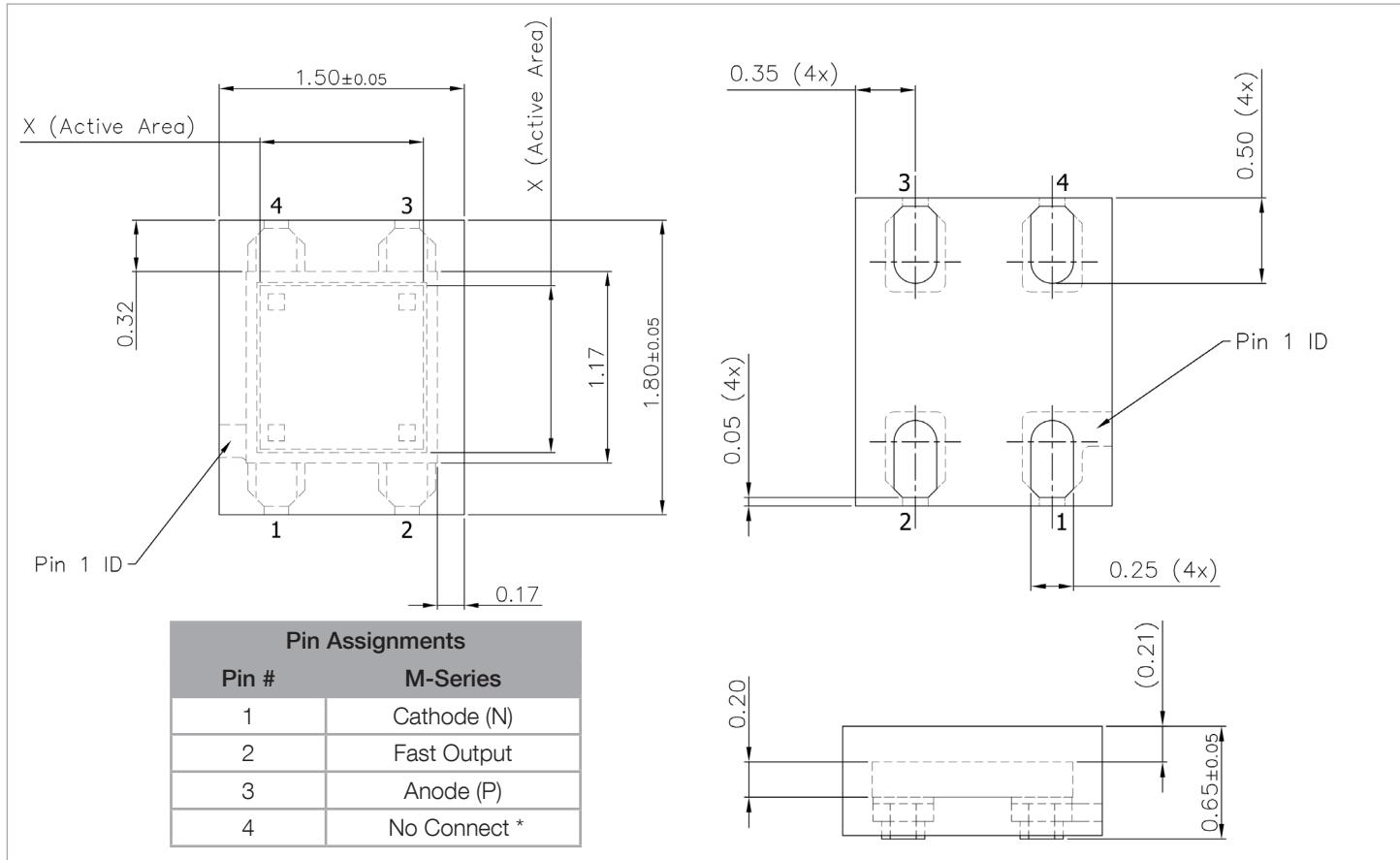


Figure 17, Solder footprint for the MicroFM-300XX-SMT part. All dimensions in mm. Fingers on pads 1-4 can be omitted in tight pitch PCB designs to better facilitate routing of signals.

MicroFM 02500 & 10000 Series SMT Package



* No Contact (NC) pin 4 should be soldered to PCB, this pin can be connected to ground but it can also be left floating without affecting the dark noise.

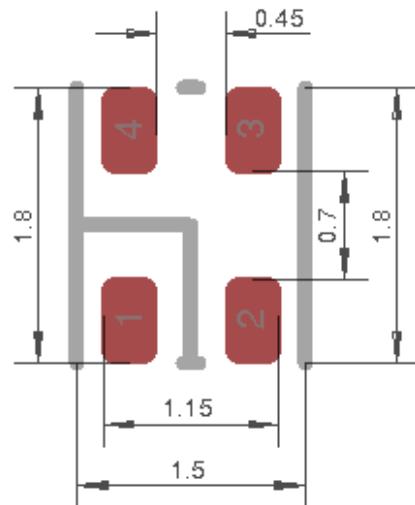
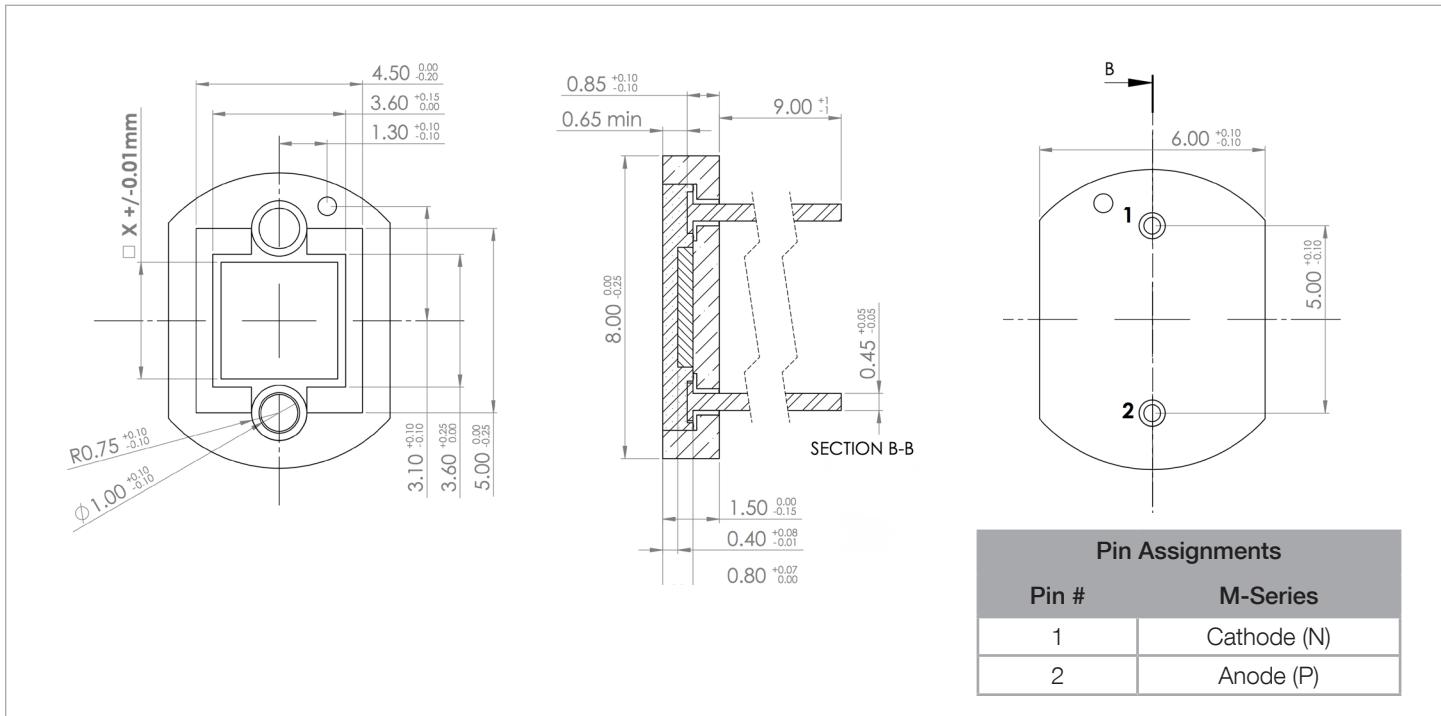
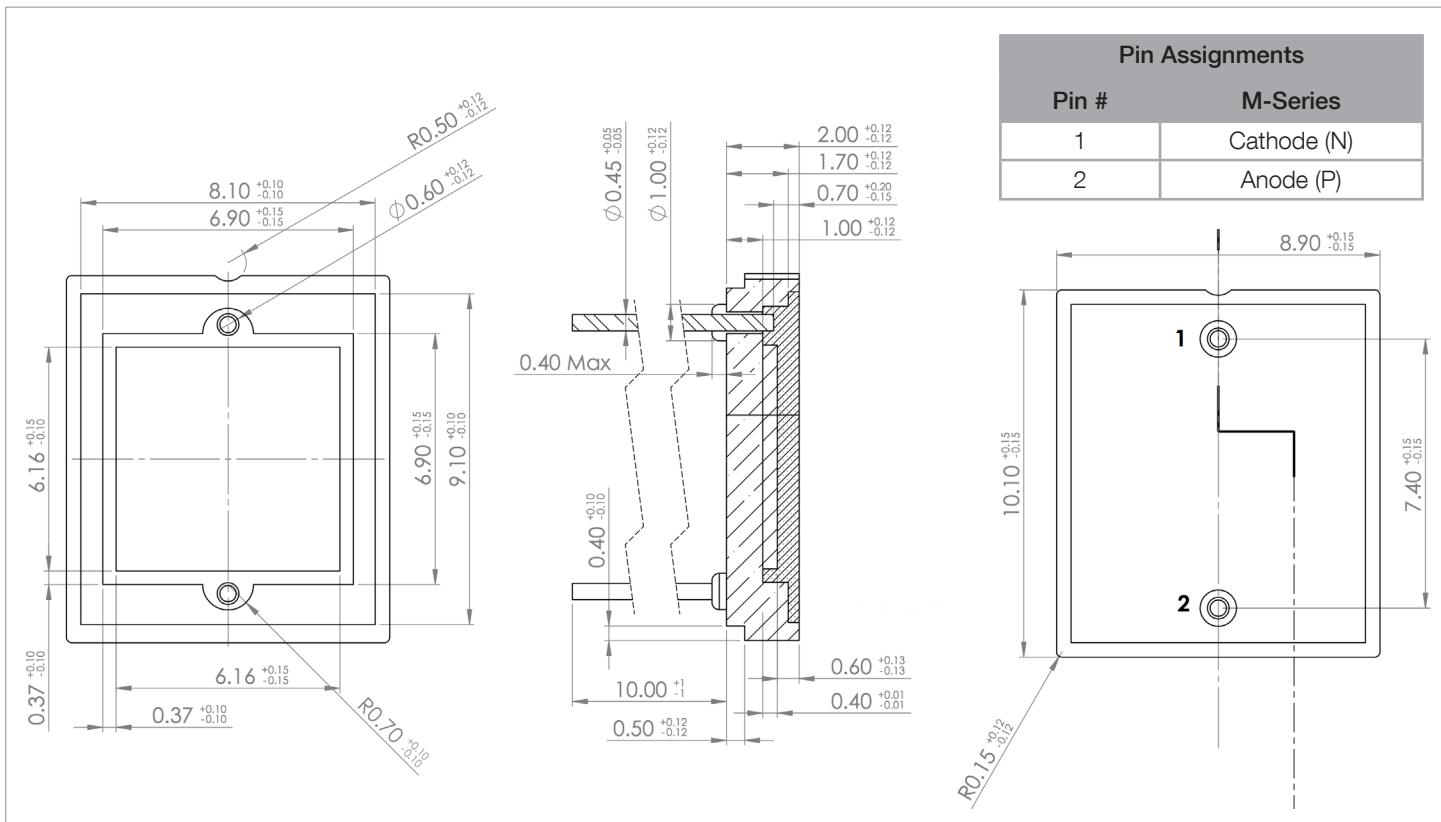


Figure 18, Solder footprint for the MicroFM-100XX-SMT part. All dimensions in mm.

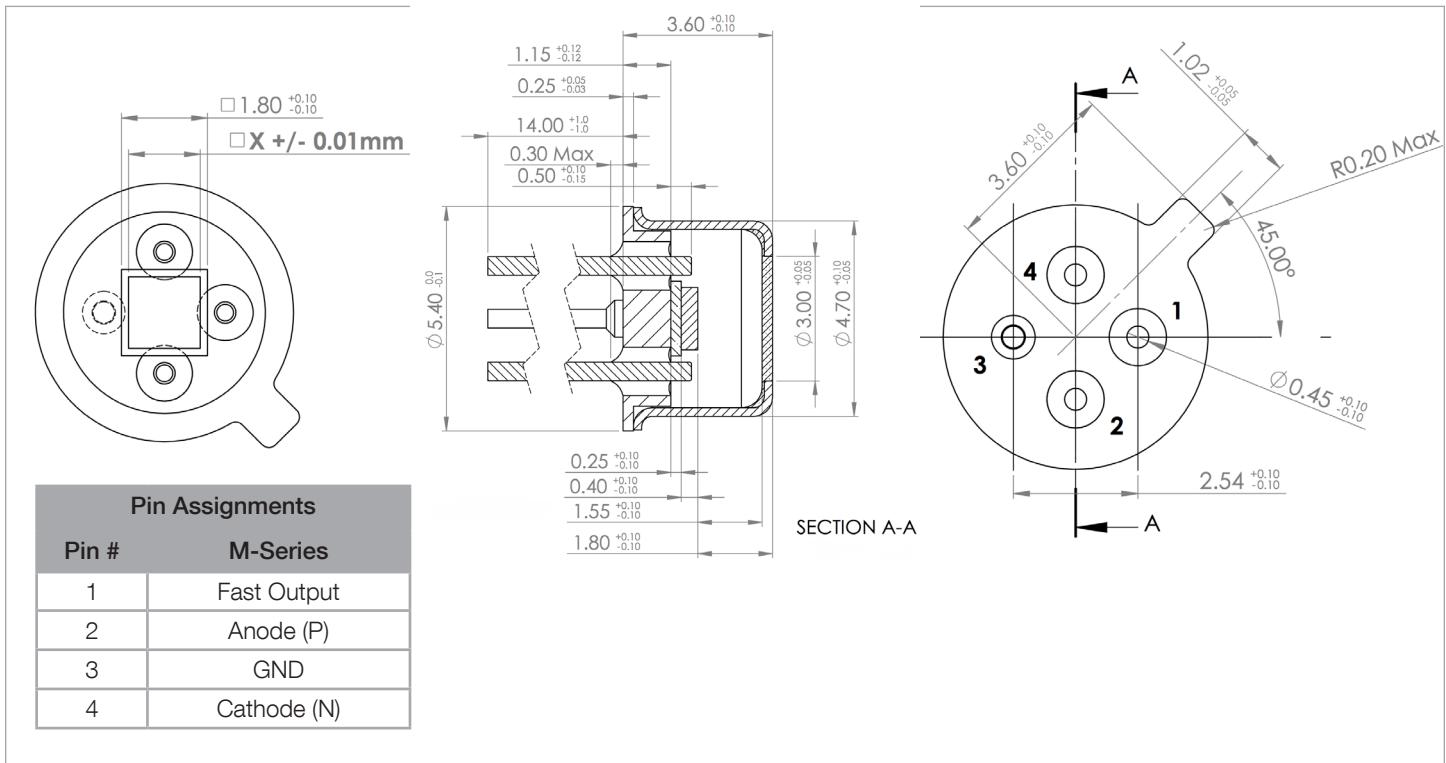
MicroSM 30000 (and 10000) Series X13 Ceramic Package
(Note 10000 series package is same but with smaller sensor size.)



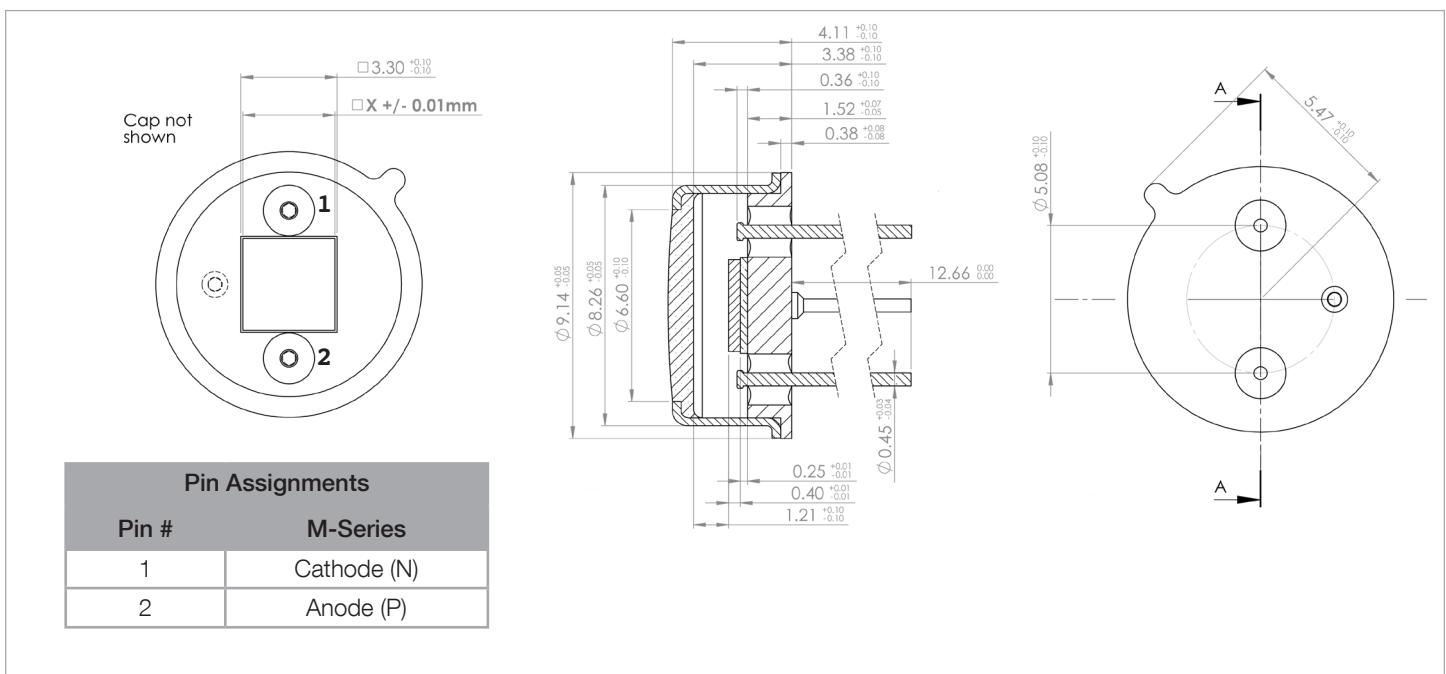
MicroSM 60000 Series X13 Ceramic Package



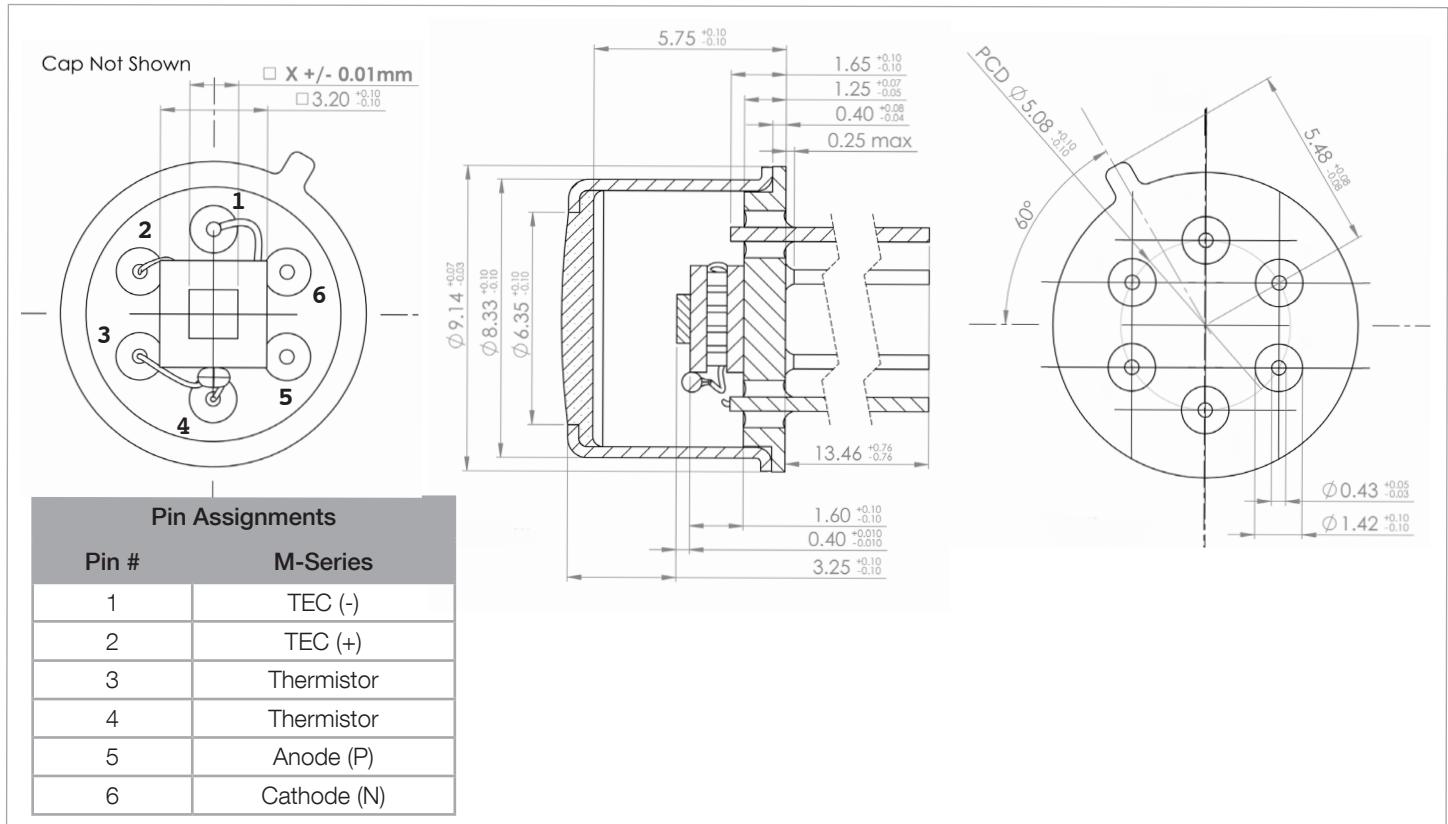
MicroFM 10000 Series X18 Package



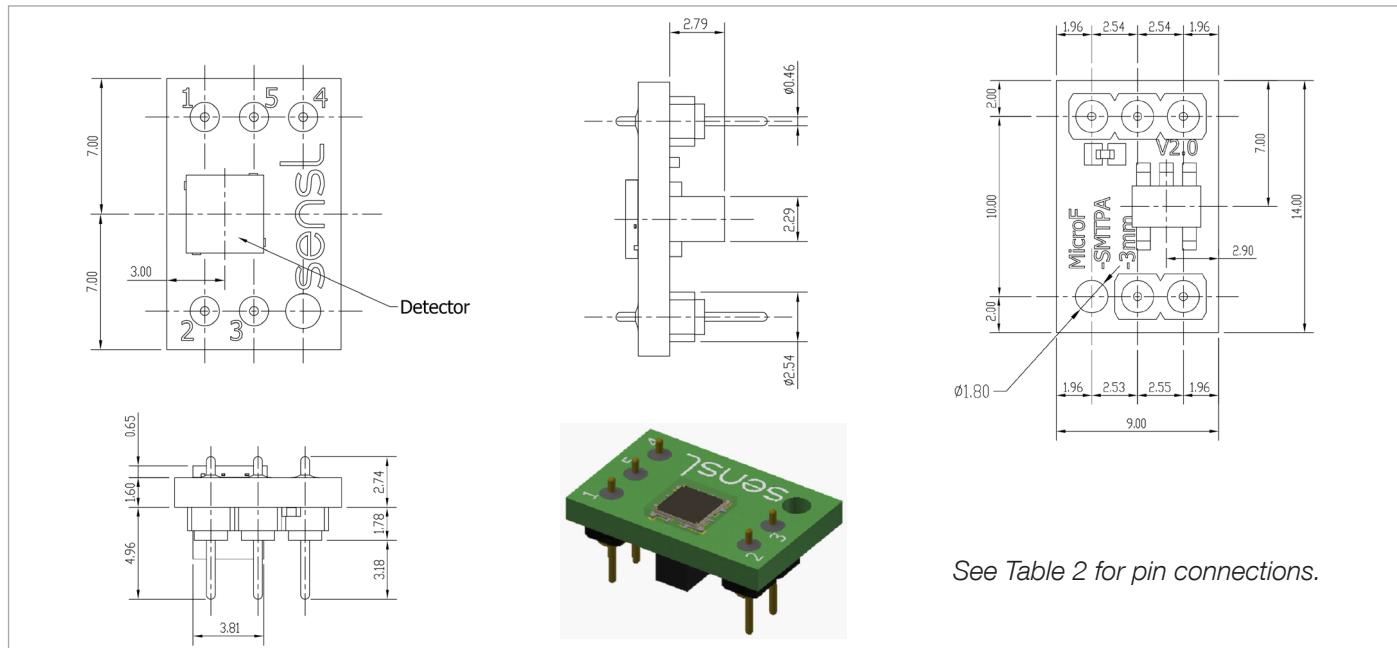
MicroSM 30000 Series X05 Package



MicroSM 30000 Series X39 Package

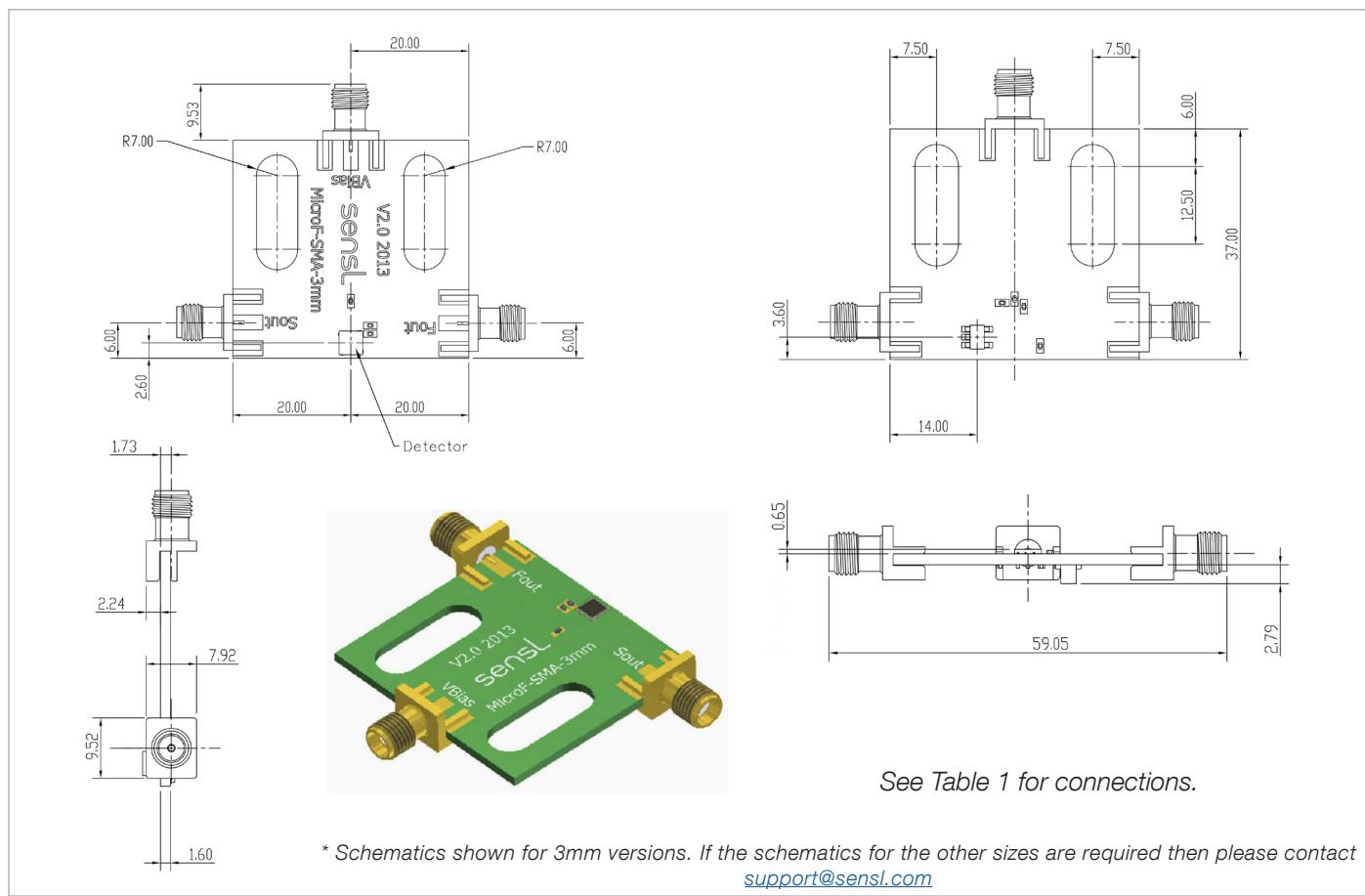


*MicroFM-SMTPA Board**



See Table 2 for pin connections.

*MicroFM-SMA Board**



See Table 1 for connections.

* Schematics shown for 3mm versions. If the schematics for the other sizes are required then please contact support@sensl.com

Handling and Soldering

Safe Handling of Sensors

- When unpacking, care should be taken to prevent dropping or misorienting the sensors. The specific items contained in the package and the type of packaging will depend on the parts ordered.
- Remember that the SiPM is a sensitive optoelectronic instrument; always handle the sensor as carefully as possible.
- The sensor should be disconnected from the bias supply when not in use.
- SiPM sensors are ESD sensitive. The following precautions are recommended:



- Ensure that personal grounding, environmental controls and work surfaces are compliant with recommendations in JESD625.
- Ensure that all personnel handling these devices are trained according to the recommendations in JESD625.
- Devices must be placed in an ESD approved carrier during transport through an uncontrolled area.

Package Summary

Table 3 summarizes packages and product type. In the following sections, handling and soldering advice is given for each package type.

Package type	Product type	MSL*	Reflow Solder?
SMT - Tape & Reel	FM	3	Y
SMT - Cut Tape	FM	4	Y
SMT - Tray	FM	N/A	Y**
X18	FM	N/A	N
X13	SM	N/A	N
X05	SM	N/A	N
X39	SM	N/A	N

Table 3, Summary of which package types are associated with which product type.

*See Table 4 for definition

** Sensors shipped in a tray require a bake according to J-STD-20, prior to reflow soldering

SMT Package

A dedicated [SMT Handling and Soldering Tech Note](#) is available that contains in depth information on the storage and use of the SMT parts, including the CAD for the tape and reels.

The SMT package is compatible with standard reflow solder processes (J-STD-20) and so is ideal for high volume manufacturing. The recommended solder footprints are shown in the Schematics section of this document. If the SMT part is being assembled into an array, the advice in the [SMT Array Tech Note](#) should be followed.

SMT SiPM sensors are shipped in moisture barrier bags (MBB) according to the J-STD 033 standard. An unopened MBB should be stored at a temperature below 40°C with humidity below 90%RH. After the MBB has been opened, the devices must be reflow soldered within a period of time depending on the moisture sensitivity level (MSL). SensL SMT Tape & Reel are MSL 3, cut tape SMT are MSL 4 and SMT sensors shipped in trays require a bake prior to reflow soldering. See Table 4 for details.

MSL	Exposure time	Condition	Applicable SMT shipping format
3	168 hours	≤30 °C/60% RH	Tape and reel
4	72 hours	≤30 °C/60% RH	Cut tape and partial reels

Table 4, MSL definitions applicable to SensL products (reference J-STD 020).

All SMT shipped on tray do not have an MSL rating and should be baked prior to placement on PCB. Please discuss this with your contract manufacture for their recommended baking cycle which adheres to IPC/JEDEC J-STD-20 MSL Classification. Note the temperature of the bake should not exceed the recommended operating temperature of the product listed in product's datasheet.

Exposure to solvents such as **concentrated** isopropyl alcohol (propan-2-ol) or commercial flux removal fluids such as Fluxene will cause severe, irreversible damage to the MLP packages. If cleaning is necessary, a 20% solution of isopropyl alcohol can be used. Further details on cleaning can be found in the [SMT Handling Guide](#).

Creating Arrays of SMT Sensors

If multiple SMT parts are to be mounted in close proximity (e.g. 1D or 2D arrays), the following recommendations may be helpful. By following this recommendations, a planarity of 0.09% to 0.53% can be achieved.

- Minimum spacing between SMT parts of 200µm.
- Use of FR4 PCB as the substrate material
- Use commercial automatic placement machines to achieve the necessary placement accuracy to give the above spacing and planarity.
- Take into account the MSL 3 specifications of the SMT devices when assembling.
- Hold the PCB board in a rigid frame to avoid warping due to the heat process.
- The user can refer to the additional [Tech Note](#) on this subject.

X18 Package

The X18 (TO-18 can) package has through-hole pins and hand-soldering is recommended. The SiPM can be damaged by excessive heat and so it is important that due care be given to temperature and dwell time when soldering the X18 products. A maximum temperature of **260°C for no more than 10 seconds** is recommended. More details can be found in the [Hand Soldering Guide Tech Note](#).

X13 Package

The X13 ceramic package has through-hole pins and hand-soldering is recommended. The SiPM can be damaged by excessive heat and so it is important that due care be given to temperature and dwell time when soldering the X13 products. A maximum temperature of **260°C for no more than 5 seconds, applied at a distance of 2mm from the ceramic base** is recommended. More details can be found in the [Hand Soldering Guide Tech Note](#).

X05 Package

The X05 (TO-05 can) package has through-hole pins and hand-soldering is recommended. The SiPM can be damaged by excessive heat and so it is important that due care be given to temperature and dwell time when soldering the X05 products. A maximum temperature of **260°C for no more than 10 seconds** is recommended. More details can be found in the [Hand Soldering Guide Tech Note](#).

'Not Connected' (NC) Pads and Pins

Common PCB design practice is to ground any floating pins or pads such as those labelled 'NC'. Grounding the pin helps shielding and can reduce noise interference from external sources (EMI/RF).

X39 Package

The X39 (TO-39 can) package has through-hole pins and hand-soldering is recommended. The SiPM can be damaged by excessive heat and so it is important that due care be given to temperature and dwell time when soldering the X39 products. A maximum temperature of **260°C for no more than 10 seconds** is recommended. More details can be found in the [Hand Soldering Guide Tech Note](#).

The MicroSM-X39 product is a 6-pin, TO-39 package housing a thermoelectric cooler (TEC). This allows the SiPM sensor to be cooled which significantly reduces the noise. The specifications for the TEC and thermistor are shown in Tables 5 and 6 respectively.

NB: Specifications for the TEC are given at the package hot side temperature $T_{hot} = 300K$. The environment in the package is N_2 .

Rating		Value
Maximum Current	I_{max}	1.2A
Maximum Voltage Drop	U_{max}	1.3V
Maximum ΔT	ΔT_{max}	64K
Maximum Cooling Capacity	Q_{max}	0.94W

Table 5, X39 TEC specifications

Rating	Value
Resistance @ 25°C, R	2.2k Ω
Temperature coefficient @298K	-5.06 %/K
Beta Constant, β	4500K ⁻¹

Table 6, X39 thermistor specifications

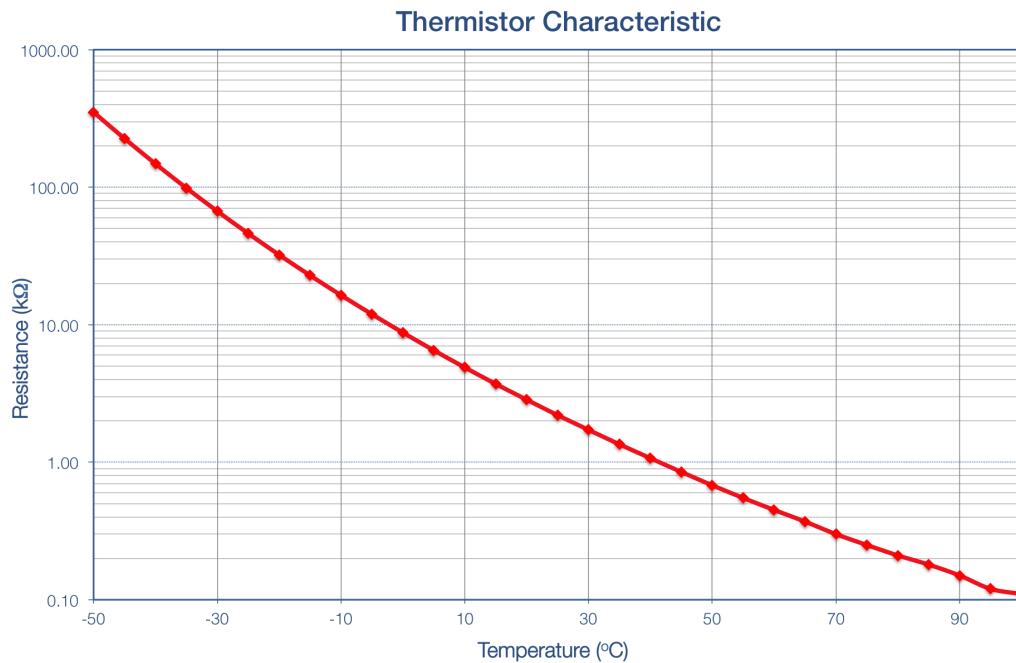


Figure 19, Thermistor resistance as a function of temperature.

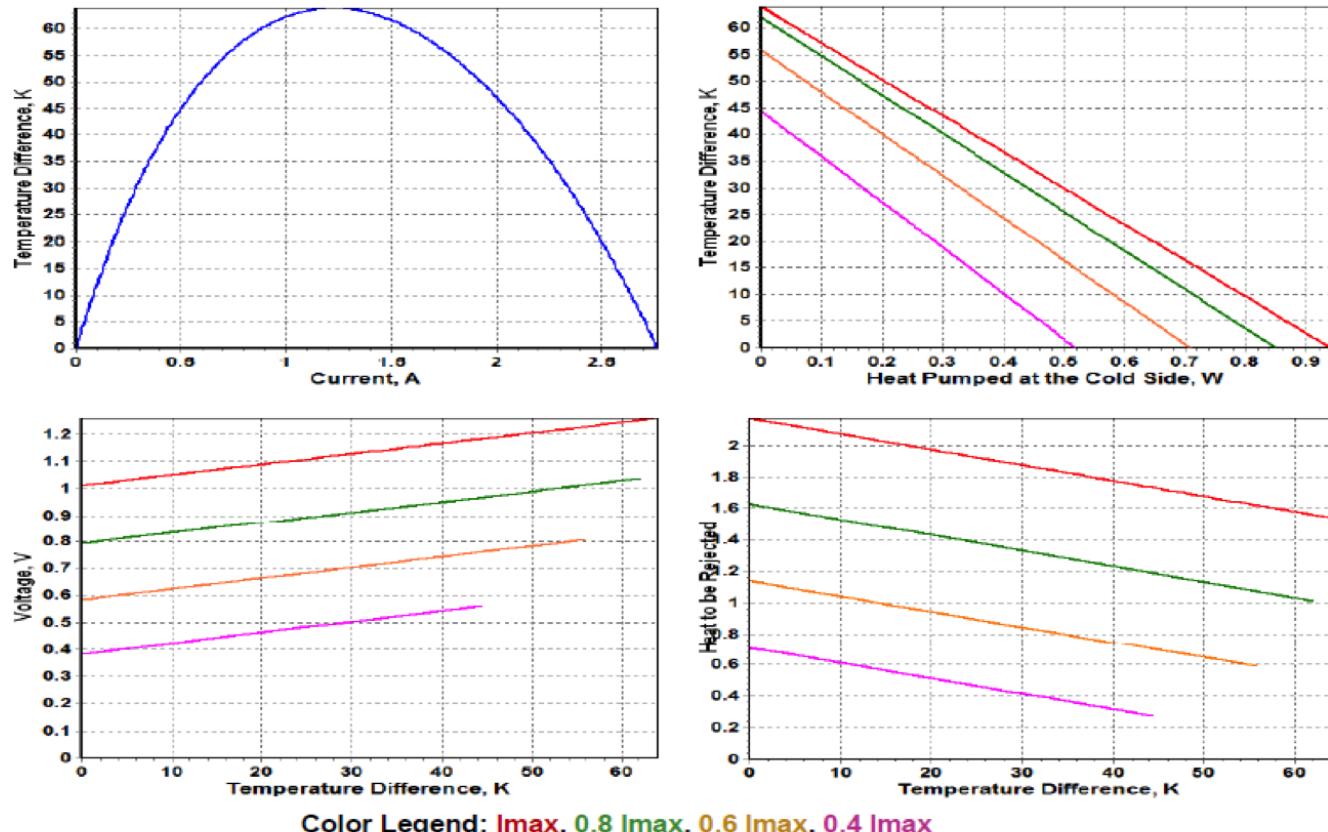


Figure 20, Performance specification plots for the X39 TEC

Further Help

If more help is required in the set-up or operation of M-Series sensors, there are several SensL resources that can help.

- The [M-Series Datasheet](#) contains more detailed information on the physical and performance characteristics of the sensors.
- The Micro-EVB is a product option for the MicroSM series of sensors, and users may find it useful to consult its [Product Brief](#) and [User Manual](#).

A variety of Tech Notes are available on the website, www.sensl.com, such as:

- The Technical Note “[Introduction to SiPM](#)” which provides an over-view of the MicroSM SiPM technology, how it works and how performance parameters are affected by different settings.
- The [MicroSM Quickstart Experimental Guide](#).
- A guide to [handling and soldering SMT packages](#).
- A guide to [hand soldering](#) through-hole SensL sensor products.
- A guide on creating [arrays of close-packed SMT sensors](#).
- An extensive [library](#) of technical and scientific papers on the use of SensL SiPM sensors.

If additional help is needed, please contact support@sensl.com

Appendix A - Alternative Biasing in Fast Mode

When using one of the MicroFM products in *fast mode*, it is recommended to use either of the biasing schemes shown in Figures 6 or 7. However, a negative bias can be applied to the anode (substrate) as in Figure 22, without any change in performance. In this case, care must be taken to ensure good decoupling of the bias voltage at the device since the substrate is the return path for the fast signal. If this biasing configuration is required, it is recommended that a 10 nF (50 V) ceramic SMT decoupling capacitor with low ESR is placed as close to the anode as possible.

Without suitable decoupling the *fast output* pulse can suffer from ringing and pulse shape distortion when the negatively biased anode configuration is used.

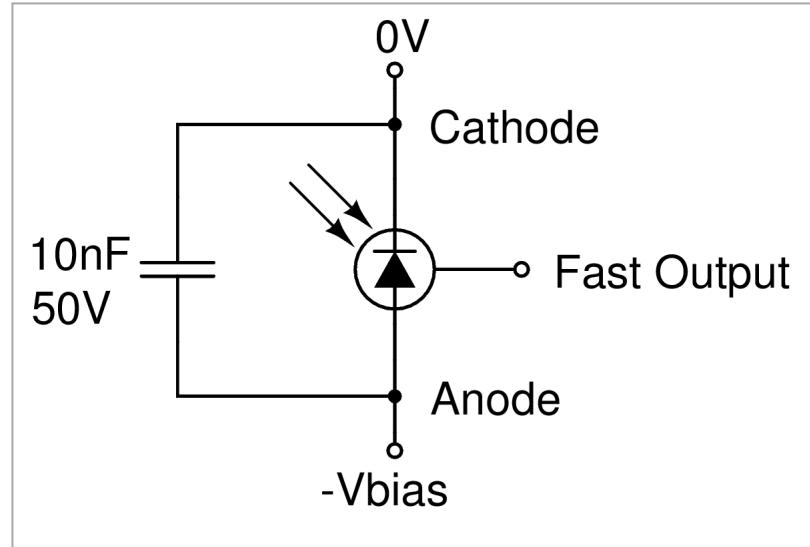


Figure 21, Alternative biasing - decoupling required.